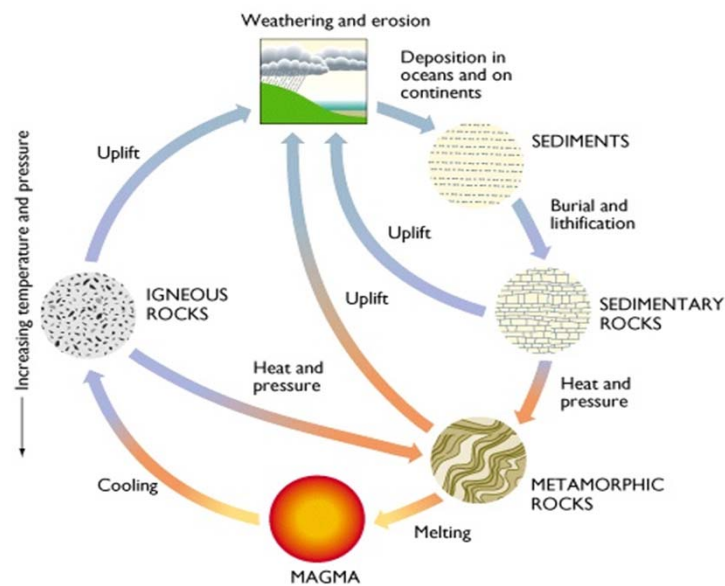


Sedimentary Rocks



The Rock Cycle



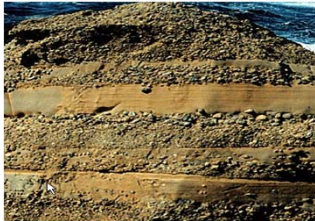
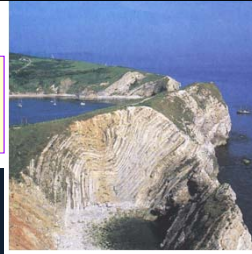
Sedimentary Rocks

The word **sedimentary** is derived from the Latin word **sedimentum**, which means “settling” referring out to solid material from fluids (water or air).

Sedimentary rocks are formed by the accumulation and consolidation of sediments ...

but what are sediments?

When rocks are weathered and eroded, they usually break down into component mineral grains or particles of rock. When these fragments find their way into channels, wadis etc. and get carried long distances, we call them **sediments**



Accumulations of precipitated material and organic remains are also called sediments.

Sediments and sedimentary rocks cover about 70 percent of the continents and most of the ocean floor. They make up about 5 % by volume of the Earth's crust. They are often found in horizontal layers called “beds”.

Sedimentary Rocks

➤ Importance of Sedimentary Rocks:

1. 70 % of the rocks at the Earth's surface are sedimentary in origin (sandstone, limestone, shale, ironstone, coal, chert).
2. Sedimentary rocks contain the source of mineral, ground water and oil wealth.
3. Sedimentary rocks contain the record of life on Earth.
4. Studies of sedimentary rocks help understand the Earth geological history (palaeogeography, palaeoclimatology).

Sedimentary Rocks

- Studying the sedimentary rocks requires the following studies:
 - Lithology (Fieldwork) Studies.
 - Mineralogy & Geochemistry (Lab) Studies.

➤ Lithology (Fieldwork) Studies:

- Composition.
- Color.
- Texture.
- Sedimentary structures.
- Thickness.
- Fossil content.
- Boundaries and sequence stratigraphy.

➤ A stratigraphic log (vertical section) can be drawn up to include much of these field observations (called “logging a section”).

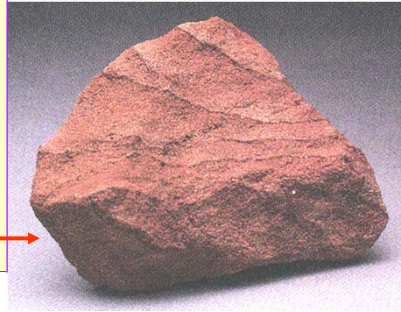
Age	Rock Unit	Bed No.	Sample No.	Lithology	Description
Middle Eocene	Mokattam Formation	8	S 11		Limestone; brownish yellow, very hard, dolomitic, ferruginous, with some marl intercalations, fossiliferous.
		7	S 10		Dolostone; brownish yellow, slightly sandy and cavernous, banded.
		6	S 9 S 8		Dolostone; yellowish brown, hard, ferruginous, highly sandy, cavernous, contains geosts, highly bioturbated.
		5	S 7		Dolostone; yellowish brown, hard, ferruginous, massive, and occasionally fractured.
		4	S 6		Dolostone; brown, porous, ferruginous, sandy at the top.
		3	S 5 S 4 S 3 S 2		Dolostone; brown, hard, highly ferruginous, argillaceous, sandy, with gypsum veins and clay nodules at the top.
		2			Sandstone; yellowish brown, hard, calcareous, ferruginous, with conglomerate band at the base.
		1	S 1		Shale; olive gray, with minute iron oxide lenses.

Sediments and sedimentary rocks

Rock particles such as gravel, sand and mud, which result from weathering processes, are called **sediments**. Examples include sands forming the sand dunes, gravels in a streambed or mud on the floor of a swamp.



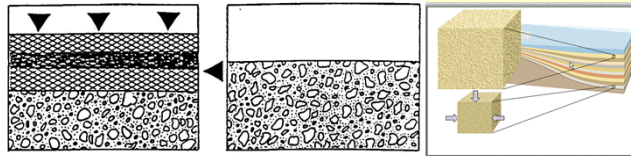
Over long periods, these sediments accumulate; the materials near the bottom are compacted and finally cemented together by mineral matter deposited in the spaces between particles forming a solid sedimentary rock.



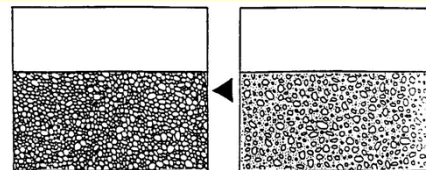
Turning sediment into sedimentary rock (LITHIFICATION)

Lithification is a process by which unconsolidated sediments are transformed into solid sedimentary rocks. This process requires two stages: **compaction** and **cementation**.

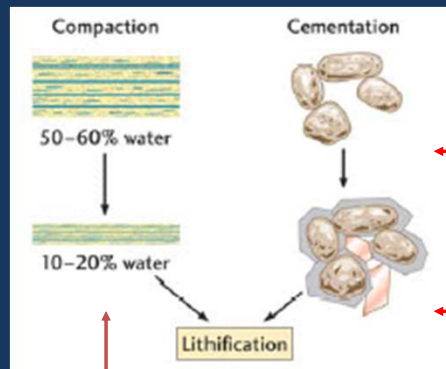
- ✓ **Compaction** results when sediments accumulate through time and the weight of the overlying sediments compresses the deeper sediments causing reduction of the total volume as well as the pore spaces of the sediments.



- ✓ **Cementation** follows compaction and results when cementing materials like calcite, silica or iron oxides, which are dissolved in water, precipitate and fill the open spaces and join the particles together.



How do sediments become sedimentary rocks?



Muddy sediments mainly lithify during squeezing (compaction)

Compaction is due to the weight of overlying sedimentary layers, so compaction effects increase with depth of burial.

Sandy and gravelly sediments lacking mud lithify by cementation

Cement is precipitated usually chemically in the pores of the sediment. Cementation is most important for sediments that lack mud.

Sedimentary System

The formation of sedimentary rocks (sedimentary system) should include the followings:

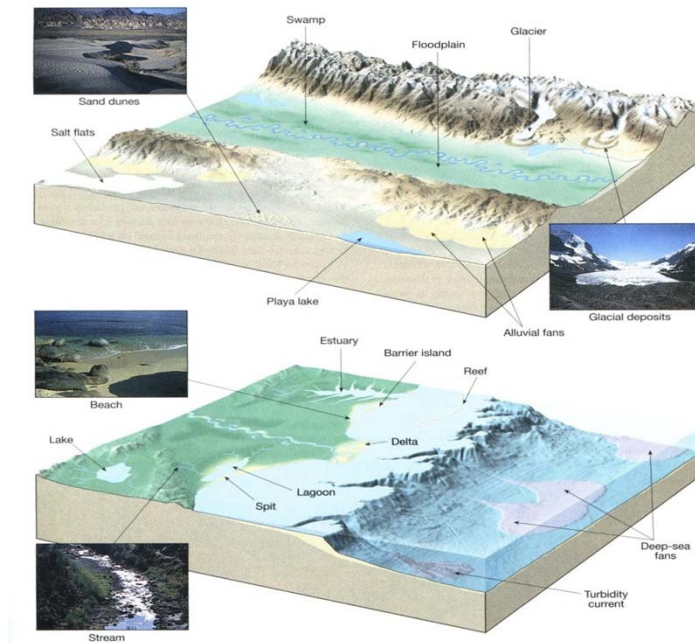
1. **Source rock type:** from which the sediment is derived and it influences the mineralogy of the final products.
2. **Weathering:** is the process by which rocks are disaggregated (mechanical weathering) or undergo chemical reactions (chemical weathering).
3. **Transport mechanism:** such as wind, ice, water, or gravity; and it influences the sorting, grain size and type of layering of the sediment.
4. **The site of deposition:** such as river, lake, ocean, or desert; and it gives differences in color, bedding, mineralogy, grain size distribution.
5. **The plate tectonic setting:** sedimentary rocks formed at convergent margins are different from those, formed at plate interiors.

Where are sediments found?

They are found in all environments affected by running water, ice or wind.
They usually accumulate in low lying areas especially those at or below sea level.

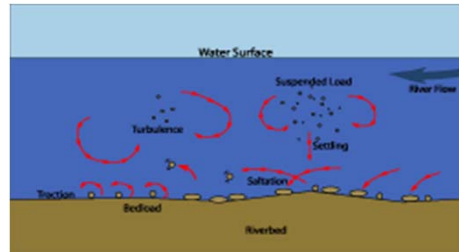


We call these sedimentary environments



How are sediments transported?

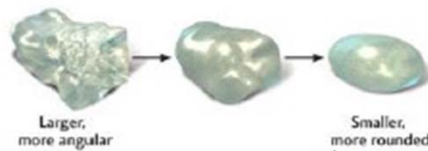
They can be transported particle by particle or as mixtures of sediment and fluid.



What happens to sediments during transport?

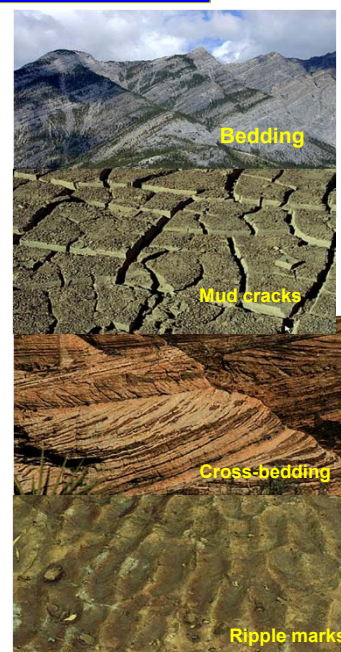
The sediment grains become more rounded and smaller with transport.

Also the softer particles ($H < 7$) are selectively removed



Textures & Structures of Sedimentary Rocks

- ✓ These are feature created when sedimentary rocks are accumulating. Because these structures reflect the character of the transporting medium, they can be used in detecting ancient environments.
- ✓ Texture describes inter-grain relationships
- ✓ Structures describes large features of sedimentary rocks
- ✓ Sedimentary Structures are divided into 4 groups:
 - ❖ Bed and Formation shapes
 - ❖ Surface structures
 - ❖ Internal structures
 - ❖ Other structures



Textures & Structures of Sedimentary Rocks

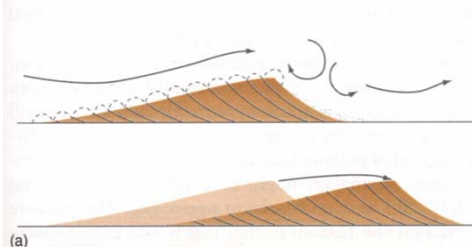
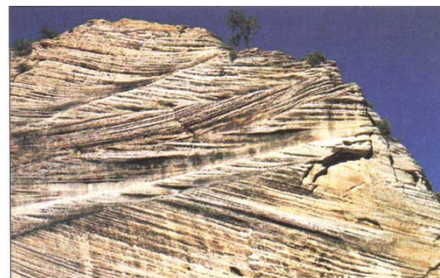
(1) Bedding:

- ✓ Bedding means the occurrence of sedimentary rocks in the form of layers called strata or beds. Beds differ from each other in grain size, mineral composition, texture. ...etc.
- ✓ The planes separating these beds are called bedding planes. These are flat surfaces along which rocks tend to separate or break. Each bedding plane marks the end of one episode of sedimentation and the beginning of another.



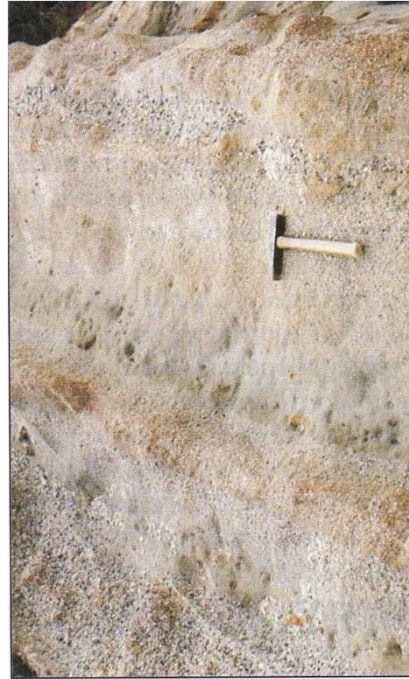
Cross bedding

Normally, most beds are originally deposited horizontal. In some case, the layers within a bed are inclined to the horizontal. This is called cross bedding and is characteristic of sand dunes; rivers deltas are stream channel deposits.



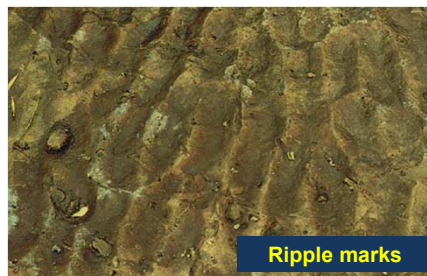
Graded Bedding

This is also another kind of bedding where the particles within a single layer gradually change from coarse at the bottom to fine at the top. It is characteristic of rapid deposition from water containing sediments of varying sizes. As the energy of water decreases, coarse grains deposit first, and in time smaller particles settle to produce graded bedding.



Ripple Marks

- ✓ Ripple marks are undulations of sand that develop on the surface of a sediment layer by the water or wind.
- ✓ Ripple marks formed by water or wind moving in one direction are called current ripple marks.
- ✓ They are asymmetric and have steep slopes in the down current side and gentle slope in the up current side.
- ✓ Ripple marks formed by the back-and forth movement of waves in a shallow near shore environments are called **oscillation ripple marks** and are usually symmetric



Mud cracks

- ✓ These are polygonal shapes result from drying and shrinkage of mud.
- ✓ They are found in shallow lakes and desert basins where mud is alternately wet and dry.



Components of Sedimentary Rocks

1. Silicate fragments and associated grain

(detrital or terrigenous materials include gravel-, sand-, silt-, and clay size fragments of preexisting silicate minerals)

2. Chemical and Biochemical precipitates

(carbonate materials)

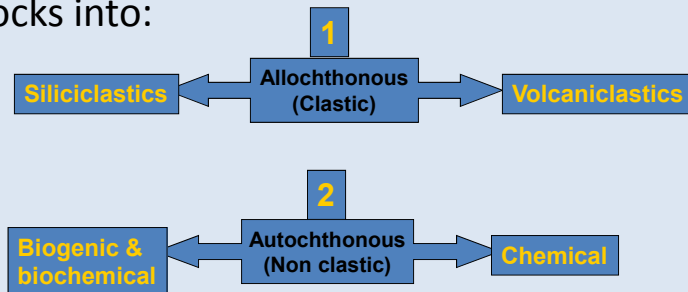
(crystalline-textured, fine-grained to aphanitic sediments produced either inorganic chemical reaction (chemical precipitates) or by chemical reactions caused by living plants or animals (biochemical precipitates).

3. Allochems

(fragments of earlier-formed precipitates (include whole fragmented fossils, oolites, organic materials, and fragments of chemically or biochemically precipitated rock).

CLASSIFICATION OF SEDIMENTARY ROCKS

- Hatch et al. (1971) classified the sedimentary rocks into:



CLASSIFICATION OF SEDIMENTARY ROCKS



There are two main types of Sedimentary Rock:

Clastic (or detrital) sedimentary rocks
e.g. sandstone, shale, conglomerate

These are composed of “clasts” that were transported as solid particles of sediment, e.g. sand, gravel, mud.



Non-clastic sedimentary rocks
e.g. chert, coal, limestone

The components of these were originally carried in solution but later were chemically precipitated or incorporated into animal bodies or plants.



What are clastic sedimentary rocks composed of?

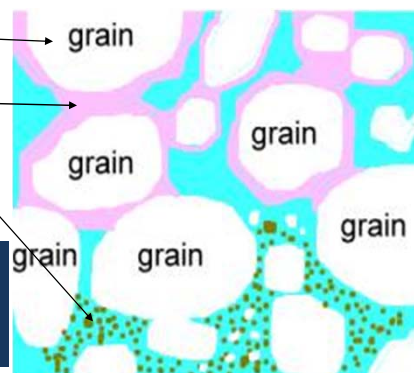
The components of a clastic sedimentary rock are:

framework grains

cement

matrix

Framework grains are the population of coarser particles. Matrix is the finer grain material that hold the framework grains together.



Cement is different to matrix.

Cement is precipitated from pore waters while **matrix** is a solid transported finer grained material. **Calcite** is a common cement.

CLASTIC SEDIMENTARY ROCKS

Particle Size Classification for Detrital Rocks

Size Ranges (millimeters)	Particle Name	Common Sediment Name	Detrital Rock
>256	Boulder	Gravel	Conglomerate or breccia
64-256	Cobble		
4-64	Pebble		
2-4	Granule		
1/16-2	Sand	Sand	Sandstone
1/256-1/16	Silt	mud	Shale or mudstone
<1/256	Clay		

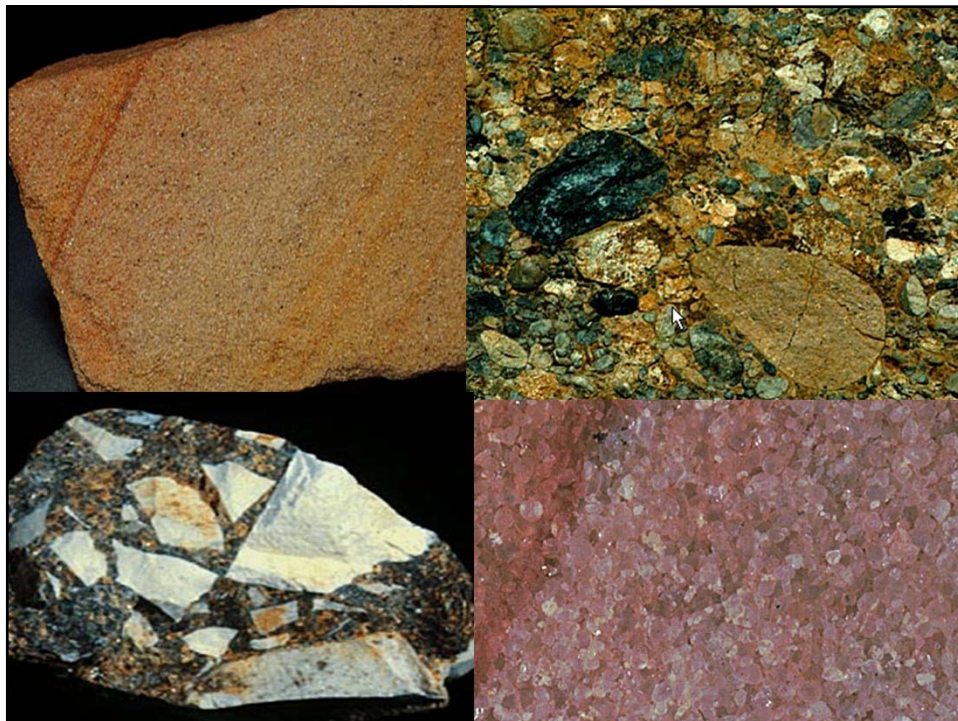
A rock is named by which of these particle sizes is dominant, i.e.

sandstone is composed mainly of **sand**

mudstone is composed mainly of **mud**

The important particle sizes are:

gravel (>2 mm)
sand (1/16 to 2 mm)
silt (1/16-1/256 mm)
clay(<1/256 mm)



COMPONENTS OF SILICICLASTIC SEDIMENTS

They include:

1. Detrital grains
 2. Matrix
 3. Authigenic minerals
 4. Cements
- } precipitated after deposition

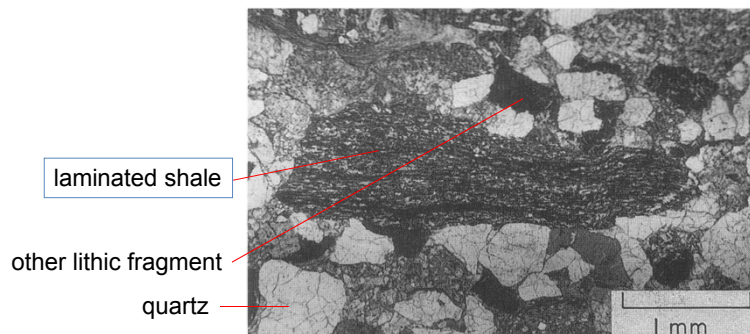
- Detrital grains include
 - rock fragments
 - quartz
 - feldspar
 - micas and clays
 - heavy minerals
 - other constituents (carbonates, phosphates, organic matter)



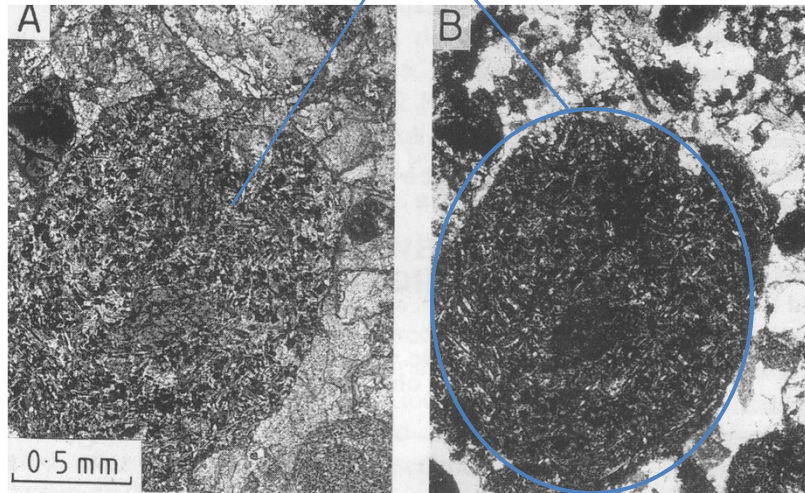
1. Rock Fragments

The rock fragments may be:

- **Intraformational**: derived from erosional reworking within the area of sedimentation.
- **Extraformational**: any rock type derived from outside the area of sedimentation due to rapid uplift and erosion of mountain belts and volcanic areas.



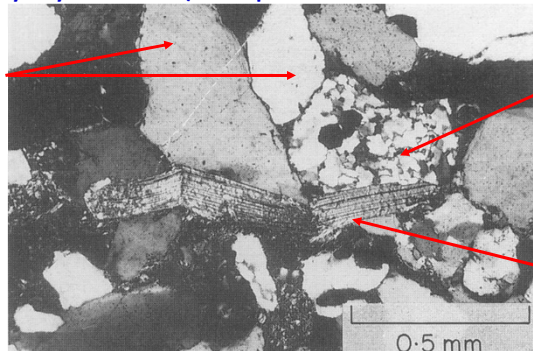
Lithic grain of volcanic origin consists of minute feldspar laths in a glassy groundmass



2. Quartz

- ✓ The most common mineral in sandstone (65% ~ 100%)
- ✓ The most stable mineral under sedimentary conditions.
- ✓ Derived mainly from granite, gneiss and schist.
- ✓ There are two types of quartz grains
 - ✓ 1- Monocrystalline (composed of a single crystal)
 - ✓ 2- Polycrystalline (composed of two or more crystals)

Monocrystalline quartz grains with unit extinction



Polycrystalline quartz grain with internal sutured contacts

Flake of mica (muscovite) bent through compaction

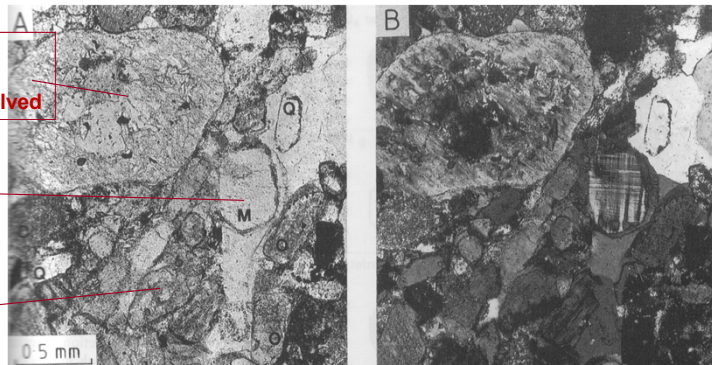
3. Feldspars

- ✓ It ranges between 10% and 15% in sandstones but sometimes reaches to 50% in the arkoses.
- ✓ It is Softer than quartz and have strong cleavage.
- ✓ Its mechanical stability less than those of quartz.
- ✓ Fluvial sediments contain more feldspar than beach or shallow-marine or aeolian sandstones.
- ✓ Low chemical stability because they are hydrolyzed easily and show dusty appearance which formed by dissolution through contact with meteoric water or replacement by clay minerals.

feldspar grain
(plagioclase):
altered & partly dissolved

feldspar grain
(microcline):
well-preserved,
x-hatching

feldspar grain
(orthoclase):
very dusty



4. Mica

- ✓ Mica includes muscovite and biotite which derived from metamorphic schist and phyllite, also from many igneous rocks.
- ✓ Biotite and muscovite are easily identified from their platey nature and parallel extinction:
 - Biotite has a brown-green pleochroism, which masks the interference colours.
 - Muscovite is colourless in plane polarized light, but has bright colours under crossed polars.

5. Clay minerals

- ✓ Clay minerals are the main component of mud rocks, and common in sandstone and siltstone matrix.
- ✓ Clay minerals include: kaolinite, illite, chlorite, smectites ..etc
- ✓ Their origin may be detrital or authigenic

6. Heavy minerals

- ✓ They are those with specific gravity > 2.9 and separated using heavy liquids (e.g. bromoform).
- ✓ Many of them are very resistant to chemical weathering and mechanical abrasion.
- ✓ They are chiefly silicates and oxides
- ✓ They include non-opaque (e.g. apatite, epidote, garnet, rutile, staurolite, tourmaline and zircon) and opaque (e.g. ilmenite and magnetite).
- ✓ Give information on provenance:
 - garnet, epidote, staurolite → from metamorphic rocks.
 - rutile, apatite, tourmaline → igneous rocks.
- ✓ Useful in correlation of stratigraphic sequences.
- ✓ Rare if compared with their quartz host but they can be concentrated in laminae or beds (called placers) through hydraulic sorting.
- ✓ Heavy minerals can be dissolved out depending on diagenetic factors such as pore-water pH and Eh, temperature and pressure.

7. Other detrital components

- ✓ Carbonate grains (fossils, ooids, peloids, intraclasts).
- ✓ Skeletal phosphate (bone fragments), glauconite and chamosite.
- ✓ Little disseminated organic matter.

CLASSIFICATION OF CONGLOMERATES AND BRECCIAS

- **Conglomerates** (subrounded to well-rounded clasts) and
- **breccias** (angular and subangular clasts) are clastic sedimentary rocks of grain size more than 2 mm.
- They can be classified according to:

Mineral composition

1. **Polymictic** conglomerates (or breccias) contain a variety of pebbles and boulders.
2. **Oligomictic** conglomerates consist of one pebble-type only.

Source

1. **Intraformational** conglomerates = clasts derived from the basin of deposition
2. **Extraformational** = pebbles derived from outside the basin.

Grains relationship

1. **Orthoconglomerates** = clast-supported.
2. **Paraconglomerates** = matrix-supported.



Sandstone

- ✓ Sandstone is the name given rocks in which sand-sized grains predominate.
- ✓ After shale, sandstone is the most abundant sedimentary rock, accounting for approximately 20 percent of the entire group.
- ✓ Sandstones form in a variety of environments and often contain significant clues about their origin, including sorting, particle shape, and composition.
- ✓ **Sorting** is the degree of similarity in particle size in a sedimentary rock. For example, if all the grains in a sample of sandstone are about the same size, the sand is considered **well sorted**. Conversely, if the rock contains mixed large and small particles, the sand is said to be **poorly sorted**.
- ✓ By studying the degree of sorting, we can learn much about the depositing current. Deposits of windblown sand are usually better sorted than deposits sorted by wave activity.
- ✓ Particles washed by waves are commonly better sorted than materials deposited by streams.
- ✓ Sediment accumulations that exhibit poor sorting usually result when particles are transported for only a relatively short time and then rapidly deposited.

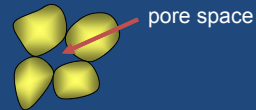
The composition of the particles is also important in the naming of sedimentary rocks.

Common framework grains are quartz, feldspar, mica and fine-grained rock particles e.g. volcanic rock. These are also included in the name of the rock

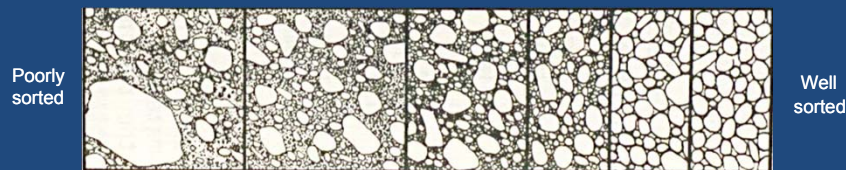
e.g. feldspathic arenite lithic wacke quartz conglomerate

Porosity, Permeability & Sorting

Sedimentary rocks lacking mud may have lots of pore spaces. These are commonly filled with fluids like water, petroleum and gas.



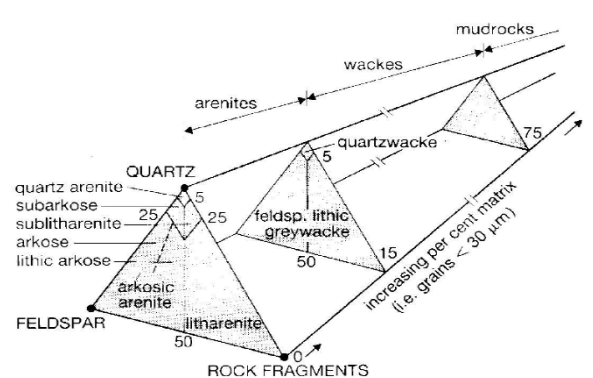
The degree of interconnectedness of the pores is a property called permeability. Its main effect is to control the rate of flow of fluids through rocks.



One of the effects of transport on sediments is the improvement in porosity of sands by the gradual separation of sand and mud. Sands (or sandstones with a narrow range of particle sizes are called well-sorted. Those with much mud are called poorly sorted.

CLASSIFICATION OF SANDSTONES

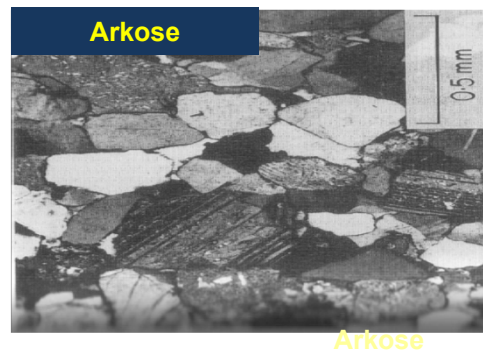
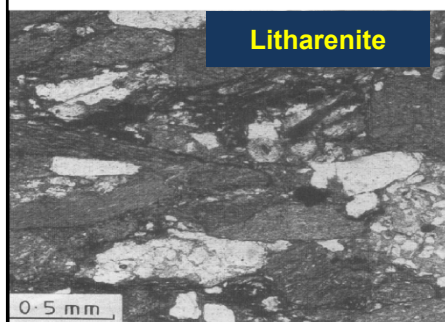
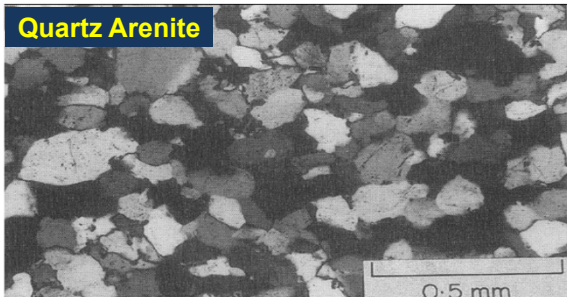
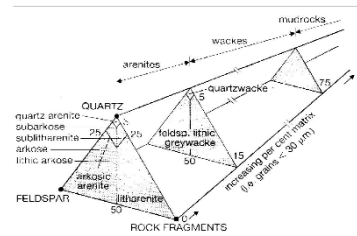
Sandstones are clastic sedimentary rocks of grain size 2-0.063 mm. They divided into two major groups: arenites and wackes



Classification of sandstones after Pettijohn et al. (1987)

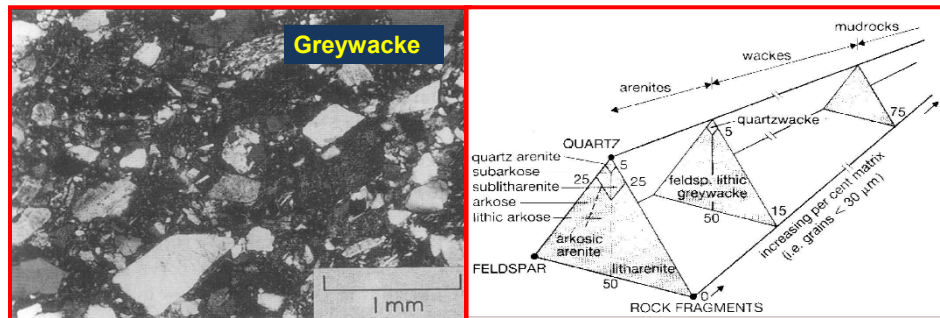
1. Arenites

- Arenites contain less than 15% matrix.
- They include the following types:
 1. quartz arenite $\geq 95\%$ quartz (the most compositionally-mature).
 2. arkosic arenite $> 25\%$ feldspars (Feldspars $>$ Lithic fragments) it is divided into arkose (with some rock fragments less than 10%) and lithicarkose (with some rock fragments between 10% to less than 25%).
 3. litharenite $> 25\%$ lithic fragments (Lithic fragments $>$ Feldspars).
- Two transitional rock types are recorded: subarkose (between quartz arenite and arkosicarenite) and sublitharenite (between quartz arenite and lithicarenite).



2. Wackes

- Wackes contain 15-75% matrix.
- They form the transitional group between arenites & mud rocks.
- They include the following types:
 - Quartzwacke $\geq 95\%$ quartz
 - Greywacke which divided into two types: feldspathic greywacke (Feldspars > Lithic fragments) and lithic greywacke (Lithic fragments > Feldspars).



EASY AND FAST

Sandstones can be easily classified according to the most dominant component such as:

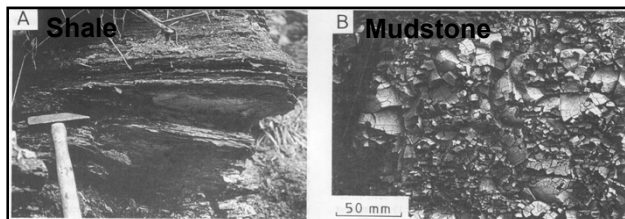
- Calcareous sandstones.
- Glauconitic sandstones.
- Argillaceous sandstones.
- Ferruginous sandstones etc....

MUDROCKS

- Mudrocks are the most abundant of all lithologies (45-55%) of sedimentary rocks.
- Mudrocks can be deposited in practically any environment although the major depositional sites are river floodplains, lakes, deltas, the more distal areas of continental shelves, basin slopes and deep-sea floors.

Types of Mudrocks

- Mudrock is a general term for clastic sedimentary rocks of grain size less than 0.063 mm
- They include the following rock-types:
 1. **Siltstone** : a sedimentary-rock with silt size (63-4 μm).
 2. **Claystone** : a sedimentary-rock dominated by clay-size materials (less than 4 μm in diameter).
 3. **Mudstone**: a blocky, non-fissile, composed of nearly equal percentage of silt and clay sizes.
 4. **Shale**: a laminated and fissile mudstone (can split into thin sheets).
 5. **Marl**: calcareous mudrocks.



Composition of Mud Rocks

- 1. **Clay minerals** (about 60%).
- 2. **Quartz** (about 30%) mostly angular grains of silt size.
- 3. Other components such as **feldspar** (4%), **calcite skeletal debris** (3%), **mica** (about 2%), and traces of **pyrite, glauconite, hematite...etc.**
- 4. **Organic Matters** (less than 1%) are common in mudrock, particularly black shales.

Origin Of Clay Minerals

1. **Inheritance:** detrital (formed in another area) → give info on the provenance.
2. **Neoformation:** formed *in situ* by direct precipitation from solution → reflect the pore-fluid chemistry, degree of leaching and temperature that existed within the sample at some stage.
3. **Transformation:** modified by ion exchange / re-arrangement → may still give info on source area and the later chemical environment.

Effect of clay authigenesis on sandstone reservoir potential:

- Kaolinite reduces reservoir porosity, but has little effect on its permeability.
- Illite reduces the permeability considerably by blocking pore throats, but has little effect on porosity.
- Replacement reactions of clay minerals affects negatively the textural maturity (more matrix).

Organic-rich Mudrocks

- Ancient organic-rich mudrocks are important **source rocks for petroleum**, if buried to suitable depths and subjected to appropriate temperatures (80 – 120 °C).
- **Organic-rich mudrocks (sometimes called carbonaceous and bituminous mudrocks):** include black shale if total organic carbon (TOC) ranges between 3 -10% and oil shale if TOC > 10%, which yield oil on heating.
- Examples include
 - Jurassic and Cretaceous bituminous shales, with organic matter derived from radiolarians and foraminifera → sourced much of the petroleum in the Middle East.
 - the organic-rich Kimmeridge clay, the chief source rock for North Sea oil.

COMPOSITIONAL MATURITY

This is determined by:

quartz + chert / feldspars + rock fragments ratios

- Immature sediment →
 - composed of unstable rock fragments & much feldspar.
 - located close to their source area, or rapidly transported and deposited with little reworking from a source area of limited physical and chemical weathering. Examples include many near-source fluvial sediments, glacial and fluvio-glacial deposits.
- Mature →
 - more stable rock fragments + some feldspar + much quartz.
- Supermature sediment →
 - composed almost entirely of quartz grains.
 - the end-product of intense weathering, abrasion or reworking, where all unstable grains have been removed.